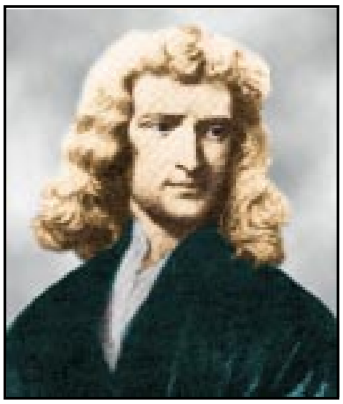
The Fourth United States Microgravity Payload

Bringing Newton Into the 21st Century...

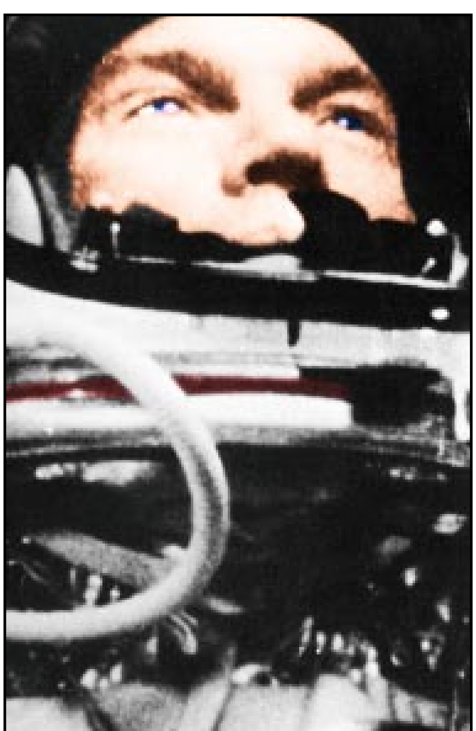
Yesterday

Sir Isaac Newton described it over 300 years ago. He was the first to realize the extent and power of it's force and that it reached well beyond the domain of Earth. That force,



Sir Issac Newton
1642-1727

he concluded, is the same force that makes an apple fall off a tree—gravity. Gravity keeps our feet firmly planted; without gravity, the very air we breathe would dissipate into space, and Earth would not orbit the Sun. The effects of gravity are truly part of our everyday lives.



John Glenn, a member of the original astronaut team, was the first U.S. astronaut to orbit the Earth in 1962.

Early space flights were very limited in the research that could be done to learn about gravity and its effects because of the short time periods in flight. Initial flights, such as those with the original astronaut team, were dedicated to solving space-flight problems rather than scientific research. The first long-term opportunities to explore the microgravity environment and conduct scientific research relatively free of the effects of gravity, came during the latter stages of NASA's first great era of discovery—the Apollo program.

Buzz Aldrin steps on the Moon during Apollo 11, 1969

The NASA microgravity program had its beginning in the experiments conducted in the later flights of Apollo, the Apollo-Soyuz Test Project, and on board Skylab, America's first space station. But preliminary experiments conducted during the 1970's were severely constrained, either by power levels and volume of the spacecraft, or the number of flight opportunities. These experiments, though simple in content, stimulated new ideas and theories about the roles of gravity in various processes on Earth.

Since the early 1980's, NASA has sent crews and payloads into orbit

Today and Tomorrow

The Shuttle provides resources for longer flights necessary for microgravity experiments, and can serve as a repair station for instruments such as the Hubble Space Telescope, shown having protective covering installed in 1993.

aboard the Shuttle. Some Shuttle flights launch a variety of permanent, specialized research facilities into space (for example, the Hubble Space Telescope); and return flights are scheduled for routine maintenance of these facilities. For other flights, improvements made aboard the Shuttle provide significant new and expanded capabilities for longer missions. Longer missions are needed for important microgravity research. Microgravity scientists are now able to monitor experiments in real-time and make any changes they wish with commands from the ground. After the mission, they can return both experiment samples and hardware to Earth.

The U.S. Microgravity Payload (USMP) program plays a key role in this valuable research. USMP investigations have produced the most important and worthwhile of all products—knowledge about the world around us.

Where Space Answers the Questions...

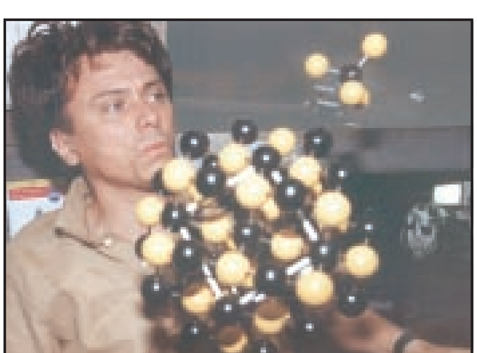
What are the secrets that gravity masks? Gravity is a dominant factor in many chemical and physical processes on Earth; but, as gravity's effects are

In space, science research is "isolated" from gravity's effects.

eliminated, what are the results? Could new alloys be formed? How would liquids of unequal densities then mix? There are many theories and experiments which predict the answers to these questions, but the only way to answer and fully understand them is to effectively eliminate gravity as a factor. Space flight offers scientists several unique characteristics for conducting experiments that erase the effects of gravity. Aboard the Shuttle, the most important of these characteristics is the state of *free-fall*, which creates a reduced-gravity, or microgravity, environment.

What is Microgravity?

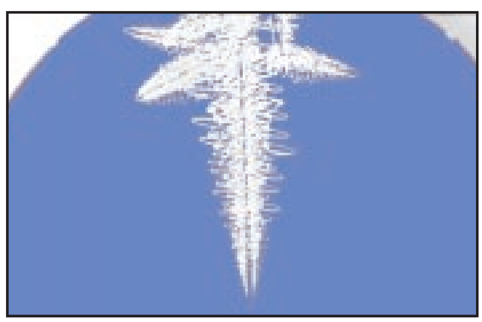
"Microgravity" really means that there is a state, or level, of very small (*micro*) gravity, or low gravity. Actually, the Shuttle orbiter escapes less than 10 percent of the Earth's surface gravity! If you drop an apple on Earth, it falls—gravity. If an astronaut drops an apple



An astronaut discusses crystal growth, while a portion of the crystal "floats" away.

on the Space Shuttle, it falls too; it just doesn't look like it's falling. That's because they're all falling to-gether; the apple, the astronaut, and the Shuttle. But they're not falling towards the Earth, they're falling around it. The Shuttle and everything in it are kept in orbit around the Earth by gravity. But since they're all falling, they're floating in a state of near weightlessness we call free-fall. But how does something fall around the Earth?

Sir Issac Newton offered this "thought experiment" to explain how an object could stay in an orbit while falling. Imagine placing a cannon at the top of a mountain. Once fired, a cannonball falls to the Earth. The greater the speed, the farther it will travel before landing. Each cannonball is acted upon by two forces: the force from the explosion propels the cannonball in a straight line, and the force of gravity pulls the cannonball down toward the Earth. The combination of the two forces causes the cannonball to travel in

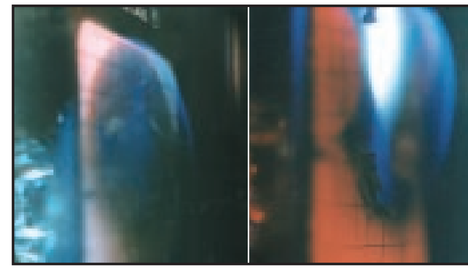


Gravity-induced flows affecting the solidification of tree-like crystals (dendrites) in metal production are absent in microgravity.

an arc, ending at the Earth's surface. If fired with the proper speed, a cannonball would continue to fall around the Earth and come back to its starting point. The cannonball would begin to circle, or orbit, the Earth. The same principle applies to the Space Shuttle, and we call it *microgravity*.

Why Do Scientists Need Microgravity to Conduct Their Experiments?

Since microgravity creates conditions that simulate the absence of gravity, several factors (known as phenomena) that are present on Earth do not exist. One of these factors is buoyancy-driven *convection*. Convection is defined as the flows or movements within a liquid or gas caused when lighter parts rise to the top and heavier parts sink to the bottom. Convection occurs on Earth, for instance, when you heat soup.



Combustion studies conducted in microgravity, without air flows affecting flame movement, reveal how flames spread.

Heated soup at the bottom of a pan expands and becomes lighter (less dense) than the soup above. It rises because the cool, dense soup is pulled down by gravity. This flowing motion does not exist in space. Microgravity eliminates the unwanted influence of gravity-induced flows. In this environment, USMP-4 researchers can conduct crystal growth, solidification, and combustion experiments to obtain answers hidden on Earth by the convection phenomena.

Another key scientific phenomenon affecting important processes on Earth is gravity-induced *pressure variation*. On Earth, for instance, experiments using fluid materials have shown that gravity-induced pressure causes a sample of fluid to have a higher pressure at the bottom of a container than at the top. Pressure changes such as this affect materials during production and can cause defects in the final product. The effects of this phenomenon can only be studied when there is a uniform pressure throughout the material sample. Space provides this setting.

How Does All This Affect Us?

The products and technologies we enjoy today came from the great minds and research of yesterday. What future will we pass on to the next generation? Science research can yield a vast range of better products, more efficient energy, and a cleaner and better environment. We will gain a better understanding of processes that affect all of us—now, and in the future. We owe these possibilities to ourselves and to those who follow.

Through Microgravity Research in the Present...

The United States Microgravity Payload (USMP) program is a series of missions developed by NASA to provide scientists with the opportunity to conduct research aboard the Shuttle in the unique microgravity environment for longer periods of time (for days, vs. minutes using other methods). More time in microgravity means that slower processes and more subtle effects can be investigated, yielding a better science return from an experiment.

Research based on precursor missions such as USMP has lead to the early initiation of a joint scientific research program aboard Russia's Mir Space Station.

USMP research has provided the foundation for advanced scientific joint investigations in laboratories on the Russian Space Station Mir and the International Space Station. Earlier USMP missions have achieved unprecedented science return and have demonstrated the advanced technology essential for conducting these joint investigations. As such, USMP science is a major part of NASA's efforts to use the attributes of the space environment to advance knowledge, to improve the quality of life on Earth, and to strengthen the foundations for continuing the exploration and utilization of space.

USMP-4 Research

Materials Science ☆☆☆☆

Materials science research seeks to understand the relationships between the processing of materials, the structure of the materials processed, and the properties displayed by those materials.

Crystal Growth: Crystals have achieved far greater value as electronic materials than they ever have as gems. Devices fabricated from semiconductor crystals are used in computers, lasers, and other applications throughout industry. These devices have revolutionized the way we live. However, highly specialized electronic devices prepared from Earth-grown crystals cannot perform to their expected limits. In complex materials processing systems, microscopic crystal defects, and composition variations significantly limit this performance.

For USMP-4, growth conditions will be controlled in a convection-free, microgravity environment, thus providing scientists the opportunity to study the crystal growth process in a way that is impossible on the Earth.

Solidification: Changing technologies require steady improvement in the physical properties of structural, electrical, and optical materials. Stronger and more adaptable metals, alloys, and composite materials are needed in aviation, power generation, and propulsion industries. To provide the knowledge to allow these necessary improvements, scientists must better understand the detailed processes that take place as materials are solidified from a molten state.

Gravity-driven convection masks fundamental growth characteristics in materials as they form. By solidifying materials in microgravity during the USMP-4 mission, scientists will gain a better understanding of these changes and apply their findings toward improvements in Earth-based manufacturing processes.

Fundamental Physics ☆☆☆

The goal of the fundamental physics program is to use the microgravity environment to help answer many questions scientists have about the most basic, natural laws that govern the behavior of materials and their properties. New knowledge about these effects will provide ideas to improve production methods, develop better products, and lower costs.The properties and behavior of some material processes cannot be studied accurately on Earth because gravity-induced pressure variations affect the sample material.

During USMP-4, a unique experiment will be conducted which will help explain how the properties of some materials (to conduct heat or transmit impulses, for example) are affected by a solid surface.

Taking advantage of the uniform pressure found in microgravity, very precise measurements will be taken of liquid helium's heat capacity near its "superfluid" point. From these measurements, scientists will apply their analysis to current theories about the laws that govern solids, liquids, or gases. Changes in theory will improve the technologies used that support and contribute to the competitiveness of American industry.

Combustion Science ☆☆☆☆

The practicality of advancing combustion science is obvious to all of us. Combustion plays a key role in energy, air pollution, transportation, propulsion, global environmental heating, and materials processing.

The Microgravity Glovebox, located in the Shuttle Middeck, will be used on USMP-4 to conduct investigations involving both materials science (studies in solidification) and combustion science. Studies into the effects of air flows on the stability of flames are planned during the mission. The capability to perform combustion investigations in microgravity will prove to be a vital tool in helping complete our understanding of combustion processes.

For the Fourth U.S. Microgravity Payload mission, six experiments will be located in the Shuttle payload bay; and three additional investigations will use the Microgravity Glovebox located in the Shuttle Middeck area. Scientists are expecting the 16-day mission to provide them with excellent scientific return.

1

Matérial pour I'Etude des Phénomenes Intéressant la Solidification sur Terre et en Orbite (MEPHISTO):

MEPHISTO is a cooperative American and French investigation of the fundamentals of crystal growth, using a materials processing furnace designed and built by the French. Scientists will study changes in solidification rates, temperature, and interface shape of an alloy to understand how these changes affect composition and properties of the metal produced.

2

Space Acceleration Measurement System (SAMS):

The objective of SAMS is to measure microgravity disturbances (vibrations) on the USMP carrier that can affect sensitive microgravity investigations. Both the crew and ground-based scientists can see these disturbances in real-time by using a computer and monitor connected to a direct feed of SAMS sensor information. The crew can see a graphic line chart showing the vibrations they cause during their normal daily activities and adjust their activities to minimize unwanted vibrations that affect the microgravity experiments. Scientists on the ground will assess these disturbances and their influence on experiment results.

3

Confined Helium Experiment (CHeX): The thermal properties of materials (such as the ability to conduct electrical impulses at varying temperatures or the capacity to absorb heat) have different values, depending on how far away from a surface or interface the measurement is being made. This so called "finite size effect" is currently an active research area in fundamental physics. CHeX will perform a high-resolution measurement of the finite size effect using a sample of liquid helium, confined to a thickness of .002 inches and held at two degrees above absolute zero. The results from CHeX will help scientists understand the degree to which surfaces influence properties of materials used in manufacturing processes on Earth.

4

Orbital Acceleration Research Experiment (OARE): On orbit, OARE will record the magnitude and location of very low-frequency Shuttle accelerations and disturbances with very precise measurements. The data will be used by scientists on the ground to request changes in Shuttle orientations to obtain the required experiment conditions to perfect the crystal growth. Post-mission they can analyze the parameters of each orientation and how they influenced the results of experiments.

5

Isothermal Dendritic Growth Experiment (IDGE): Most molten metal products solidify by forming tiny tree-like crystalline forms called dendrites; and the size, shape, and orientation of the dendrites can determine the strength and durability of the products. The IDGE is designed to test current theories and assumptions concerning dendritic growth rate and shape, in order to develop the understanding needed to control these same characteristics on Earth.

6

Advanced Automated Directional Solidification Furnace (AADSF): The AADSF is a sophisticated furnace used by researchers to study the solidification of semiconductor materials in microgravity. Researchers will request changes in Shuttle orientation so that crystals can be grown with microgravity forces in a single, precise direction during the experiment. Scientists will be able to better understand how microgravity influences the solidification process of these materials and develop better methods for controlling that process during future space flights and Earth-based production.

7

Microgravity Glovebox (MGBX): The Microgravity Glovebox serves as a "mini-laboratory" facility in the Shuttle Middeck for investigations that require crew interaction and sample containment. It provides all the necessary resources and a work area for conducting investigations. The following investigations are scheduled for the MGBX during USMP-4:

Enclosed Laminar Flames (ELF): ELF combustion investigators will study an enclosed jet diffusion flame (typically used during industrial combustion processes) to determine the effects of different air flow velocities on the stability of the flame. Results of the studies will help to optimize the performance of industrial combustors, including pollutant emissions and heat transfer.

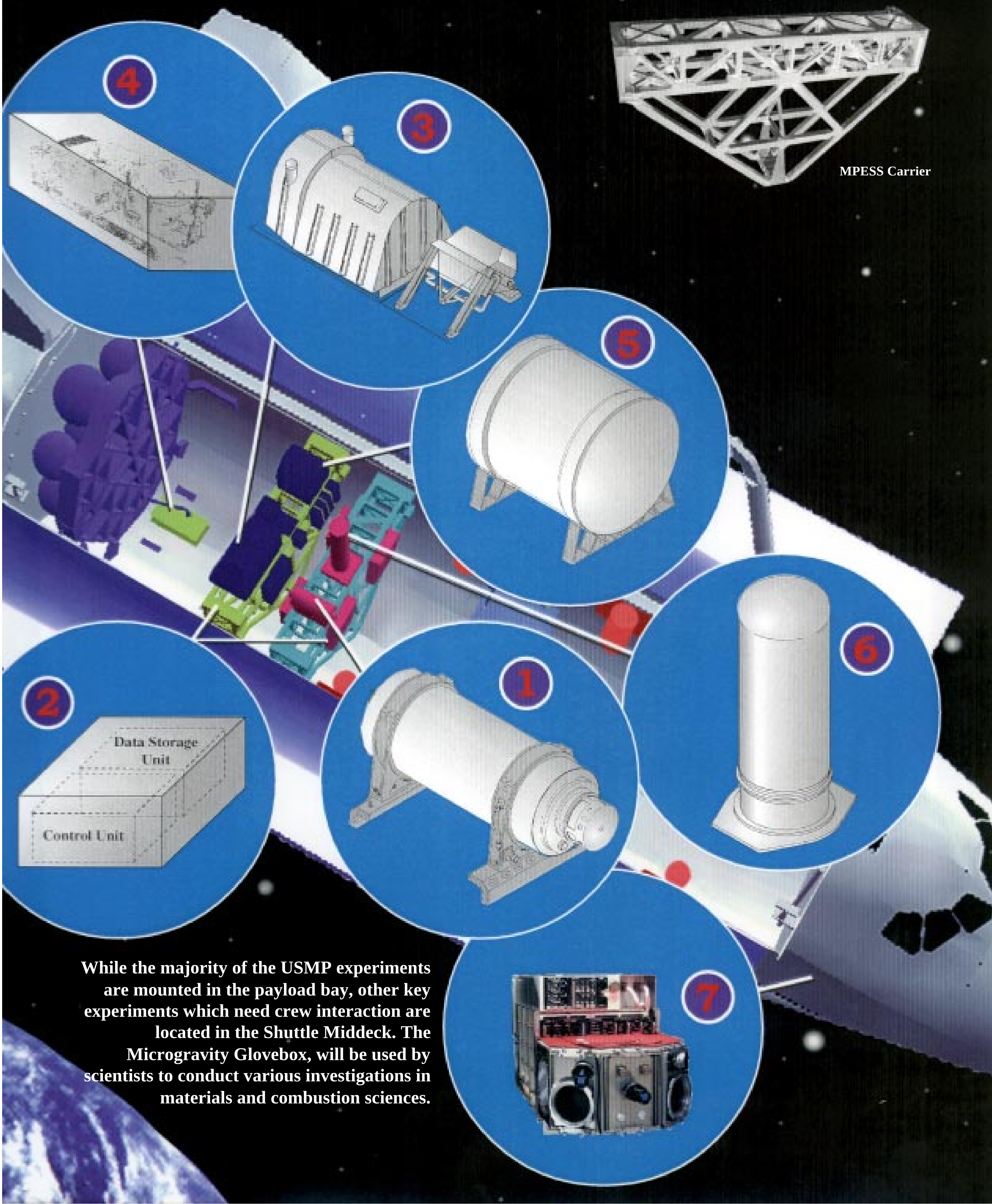
Particle Engulfment and Pushing by Solidifying Interfaces (PEP): Processing of metal composite materials uses the properties of various components to attain the desired composite strength—strength dependent upon the even dispersion of particles throughout the metal. In microgravity, PEP investigators will be able to better understand the behavior and movement of these particles as the sample is frozen from one end to the other.

Wetting Characteristics of Immiscibles (WCI): Special metal alloys, known as immiscibles, contain components that do not mix uniformly or evenly in the melt (like oil and water) during the freezing (solidification) process. Previous microgravity experiments with these alloys revealed unexpected separation of their components into layers during freezing, even though gravity's effects were absent. WCI will investigate one possible cause for this segregation—droplet wetting (or coating) along the container walls during freezing.

USMP-4

The USMP-4 payload is carried aboard Multi-Purpose Experiment Support Structures (MPESS's) mounted in the Shuttle payload bay and spanning the width of the orbiter. Experiment hardware is mounted on the tops and sides of the structures; while USMP subsystems—providing communications, data handling, electrical power, and thermal control resources—are linked to the experiments by cables and fluid lines.

MPESS Carrier



While the majority of the USMP experiments are mounted in the payload bay, other key experiments which need crew interaction are located in the Shuttle Middeck. The Microgravity Glovebox, will be used by scientists to conduct various investigations in materials and combustion sciences.

U.S. Microgravity Payload – 4

Advanced Automated Solidification Furnace (AADSF)

Science Background

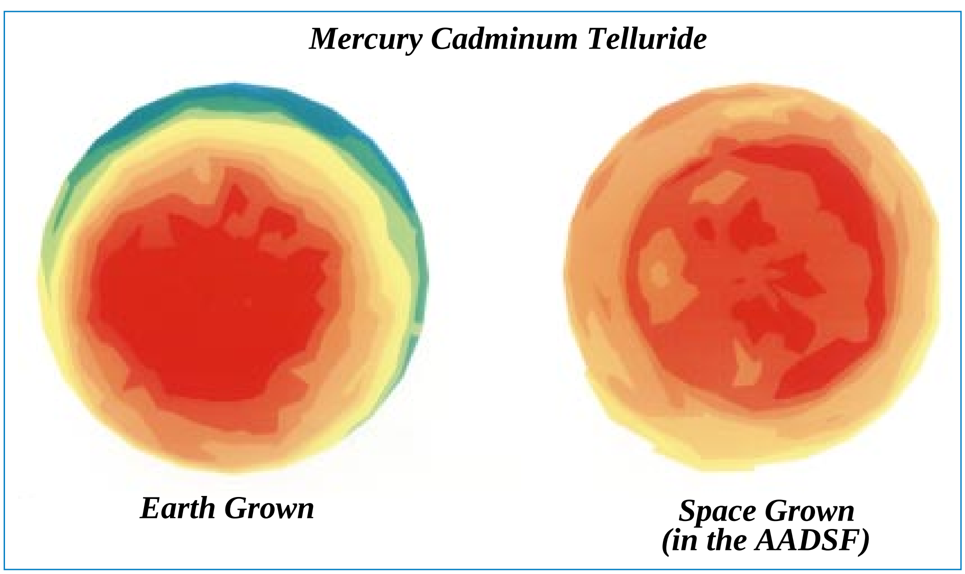
Experiences every day with a broad range of products expose people to a number of different physical forms of materials, such as solids and fluids. Just as fluids can be subdivided into liquids and gases, solids can be subdivided into crystalline or non-crystalline forms, based on the internal arrangement of their atoms or molecules. Crystalline solids have a repetitive, three-dimensional order to their internal structure: the atoms line up as though on a level surface that are then stacked upon each other.

Crystals of semiconductor materials are used in normal consumer products such as calculators and computers, and in high-technology applications such as infrared detectors and lasers. There is an increasing need for high-performance imaging systems. The performance requirements of these systems are extremely demanding, creating a need for ultra-precise crystal detectors of the best compound alloys.

The properties that make these crystals useful are related to the natural ordering of the atoms within the crystal structure. Defects in this ordering can interfere with the properties required for use in various systems. Gravity contributes to the development of these defects during production of semiconductor crystals because of the influence of factors that are always present on Earth. *Convection* (flows and movements within a material) and *sedimentation* (settling of heavier or more dense materials at the bottom with lighter materials at the top) are two of these factors.

These gravity-induced complications contribute to problems ranging from structural imperfections (physical flaws in the internal structure of the crystal) to chemical inhomogeneity (the uneven distribution of different components within the crystal). Researchers seek to better understand the mechanisms that influence the properties of materials by eliminating gravity's effects.

Any advance in the quality of these electronic materials has a great technological impact because of their application to infrared detector requirements. Additionally, the results are expected to show the way for improved ground-based crystal growth for commercial applications.



Ultra-thin wafers (about the size of a dime) cut from sample crystals of mercury cadmium telluride. Sensors fabricated from these wafers, however, must be identical and uniform in composition to be effective. The colors represent the uniformity of the composition of the wafer. Notice that the compositional uniformity is greatly improved in the space-grown sample.

Objective and Procedures

The purpose of the experiments planned for the Advanced Automated Directional Solidification

Sample Loading in the AADSF

Furnace (AADSF) is to determine how gravity-driven convection affects the composition and properties of alloys (mixtures of two or more materials, usually metal). During the USMP-4 mission, the AADSF will solidify crystals of two different alloys that are used to make infrared detectors and lasers. Lead tin telluride and mercury cadmium telluride are alloys of compound semiconductor materials that will be used as experiment samples. Although these materials are used for the same type application (detectors, etc.), their properties and compositional uniformity are affected differently during the solidification process.

One USMP-4 experiment in the AADSF, for Dr. Archibald Fripp of NASA’s Langley Research Center, will consist of two ampoules (cartridges), each with three separate samples of lead tin telluride. This experiment will examine the effect of crystal growth rate, temperature gradient (rate of change in the temperature along the sampe), and type of crystal initiation (nucleation) process, all of which affect the quality of the material.

The other experiment, for Dr. Sandor Lehoczky of NASA's Marshall Space Flight Center, will consist of one ampoule; and, is the growth of a single crystal of a mercury cadmium telluride alloy. This experiment will examine the composition and properties of the material. This particular material is designed to have unique electrical properties, and the growth technique will furnish material of exceptional compositional uniformity.

Hardware and Operations

The AADSF is a sophisticated facility for studying the directional solidification of semiconductor materials in microgravity. Directional solidification is a common method for processing metals and for growing crystals. Molten material is cooled, causing a solid to form at one end of the sample. As the sample is cooled, the solidified region grows. The interface between solid and liquid material moves from one end of the sample to the other, hence the term directional solidification.

The AADSF consists of a furnace container, an exchange mechanism for sample cartridges, and operational control and data systems. The AADSF has multiple temperature zones, each heated at a different temperature. Hotter zones are held at temperatures above the melting point of the material, while cooler zones are kept at temperatures below the melting point. The zones are controlled independently to establish a precise temperature profile down the length of the sample. Temperature sensors monitor the progress of solidification down the ampoule containing the sample material.

All experiment data is recorded and transmitted to the ground. The data is monitored in real-time by investigators so that they may request any changes during the solidification process that might optimize the crystal growth.

The AADSF has a proven "track record" and will provide scientists the opportunity to help define the future of crystal growth.

AADSF Ready for flight

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U.S. Microgravity Payload – 4

MEPHISTO

Science Background

The MEPHISTO Experiment is a cooperative American and French investigation of the fundamentals of crystal growth. MEPHISTO is a French-designed and -built materials processing furnace. Its name (Materiel pour L'Etude des PHenomenes Interessant la Solidification sur Terre et en Orbite) is French for "Materials for the Study of Interesting Phenomena of Solidification on Earth and in Orbit."

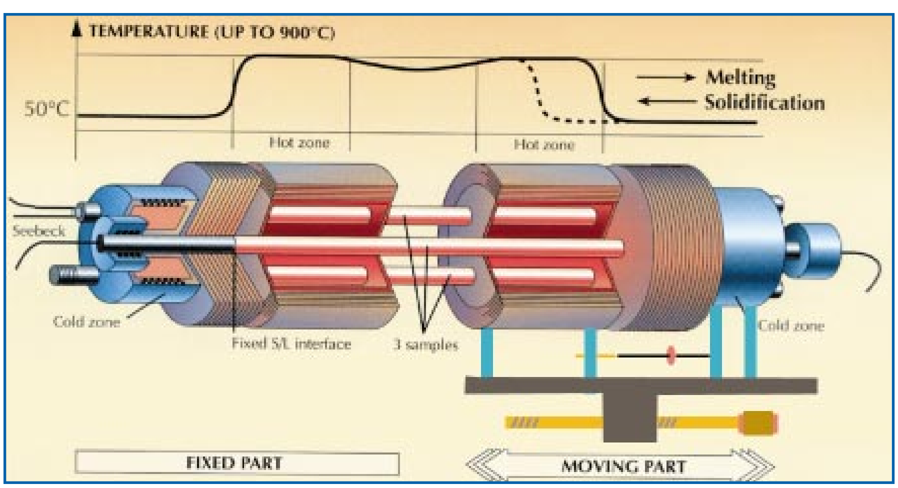
MEPHISTO experiments study solidification (also called freezing) during the growth cycle of liquid materials used for semiconductor crystals. Solidification is the process where materials change from liquid (melt) to solid. An example of the solidification process is water changing into ice.

The presence of chemical non-uniformities and physical imperfections significantly affect the quality of semiconductor crystals grown on Earth; and, as a result, affect the performance of electronic devices used in industrial, military, and home electronic equipment. The crystal growth process is complicated by gravity-induced factors. Processes cannot be properly evaluated from the results of experiments on Earth because the effects of one of these factors, *convection* (flows or movements within a liquid or gas), masks the underlying effects scientists need to study.

These flows are effectively eliminated in microgravity, making it easier to understand the growth process. This improved understanding will influence the development of techniques for growing higher quality crystals on Earth.

Objective and Procedures

There are a number of techniques for growing crystals. The method used in this experiment is known as directional solidification. In this process, the molten sample in the furnace is cooled at one end; it begins to solidify as the temperature of the liquid falls below the melting point. As cooling continues, the boundary between the solid and liquid material (the solid/liquid interface) moves from one end of the sample towards the other–hence the term directional solidification.



It is important to know the position of the interface and how fast it moves during crystal growth. Conditions at the solid/liquid interface largely determine the rate at which the crystal grows, the mechanism by which it grows, and its structure and chemical composition. These factors strongly influence the quality of the crystal and its usefulness in electronic devices. In particular, the supercooling at the solid/liquid interface is a key variable during growth. Supercooling describes the condition in which a liquid cools to below its freezing point before solidifying.

MEPHISTO will explore the effect of directional solidification in microgravity on the temperature, velocity, and shape of the solidification front of three samples growing under identical conditions. All three samples are melted and solidified simultaneously, thus providing identical thermal treatment; but different measurement techniques are made on each sample.

MEPHISTO uses a very selective technique (the Seebeck technique) to measure the temperature variations of the solidification front without disturbing the growth process. The Seebeck technique uses electrical measurements made on a sample with two solidification fronts (one stationary, one growing). The sample is cylindrical and is solid at both ends and molten in the middle. The measurements determine the temperature variations at the growing front. The shape of the growth front is marked by subjecting another sample to an electrical current pulse (the Peltier technique). At the termination of this growth process, the third sample is rapidly cooled (quenched) in order to preserve the final interface shape and composition profile which would otherwise be changed during a slow cool down.

Bismuth with small additions of tin will be studied in this experiment. These materials have a tendency to form faceted (flat faced) crystals when they solidify. Bismuth and tin also have relatively large Seebeck signals, making them good candidates for use in MEPHISTO.

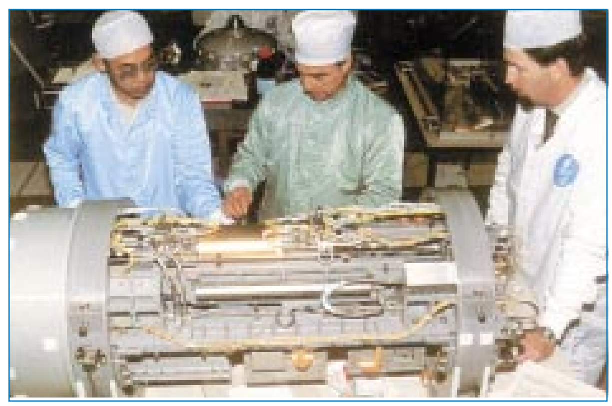
The USMP-4 experiments, in cooperation with the University of Florida, will be focused on studying the influence of the facet formation on the growth rates; and will involve more concentrated alloys than in previous flights. In addition, the experiments will include a systematic study of the effects of crystal orientation on the stability of the growth front. The real-time Seebeck measurements, Peltier interface marking, and quenching measurements will allow for the characterization of the microstructure (internal structure when viewed under a microscope) of the crystal , following the flight experiment.

Hardware and Operations

The MEPHISTO experiment instrument contains two furnaces which are heated during flight to a predetermined temperature. The instrument will simultaneously process three stationary, rod-shaped samples (5.88 mm in diameter and about 900 mm long). One furnace is mounted on a sliding mechanism that allows it to move back and forth; the other is in a fixed position. As the moving furnace travels towards the fixed one, the sample solidifies behind it. As it moves away from the fixed furnace, the sample melts between the two furnaces.

Numerous melting and solidification cycles will be performed under different conditions during the mission. The measurements made in space will be virtually free from gravity-induced convective flows and other complications experienced on Earth. Researchers will compare data from space and ground-based experiments to better understand solidification and the effects of gravity on the solidification process.

During the USMP-4 mission, MEPHISTO data is correlated with data from the Space Acceleration Measurement System (SAMS). Data is transmitted to scientists on the ground and the solidification conditions can be varied by commands from the ground. The data is processed real-time in the University of Florida and French laboratories and used to optimize the operating conditions for the next experiment cycle.



MEPHISTO loaded on the carrier and ready for flight

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Space Acceleration Measurement System (SAMS)

Science Background

The microgravity environment that exists in the Space Shuttle while in low-Earth orbit provides unique conditions for longer periods of time than can be achieved on Earth. Gravity is not completely absent; it is merely reduced. So, acceleration movements and vibrations do exist within the environment of the Shuttle.

Vibrations are produced from several sources, such as Shuttle jet firings, fan and refrigerator operations, and crew activities.

Crew activities during flight cause more vibrations than researchers had realized. To illustrate this, the 1996 USMP-3 mission carried a special laptop computer aboard that could be moved within crew activity areas (such as the crew's quarters, middeck area, and flight deck); and that by simply plugging into the Shuttle electronic and data systems, was linked directly to the flow of SAMS sensor information. The computer and graphic display system was used to measure the vibration effects of crew activities as they occurred within these different areas of the orbiter.

The computer displayed, within twenty seconds of each occurrence, vibrations caused by normal crew activities. As a result, the crew could see the vibrations they caused during their daily activities and could adjust them to minimize unwanted vibrations that might affect the sensitive microgravity experiments.

For the first time, both the crew and scientists on the ground could assess these disturbances and their influence on experiment results. This SAMS display will be carried again on USMP-4.

In use since 1991, the SAMS has helped scientists immeasurably in obtaining crucial microgravity environmental data. As a result of its success, NASA has manifested numerous flight opportunities for SAMS to support a variety of microgravity payloads. In addition, a SAMS unit is measuring the acceleration environment of the Mir Space Station; and, a SAMS-type system will fly on the International Space Station as a part of the Space Acceleration Measurement System-II instrument supporting microgravity experiments.

During regular crew activities, even the simple act of opening or closing stowage lockers causes vibrations that can affect microgravity science.

Objective and Procedures

Being able to measure variations in the microgravity environment allows scientists to evaluate the effects of space flight on their experiments. To accomplish this, the Space Acceleration Measurement System (SAMS) senses and records vibrations at several locations during a Space Shuttle mission. SAMS supports USMP-4 researchers by making accurate measurements of vibrations at five locations near and on the microgravity experiment hardware.

The SAMS measures disturbances with sensors called accelerometers, and records the disturbance magnitude and the timing on SAMS computer hard disk drives for later analysis.

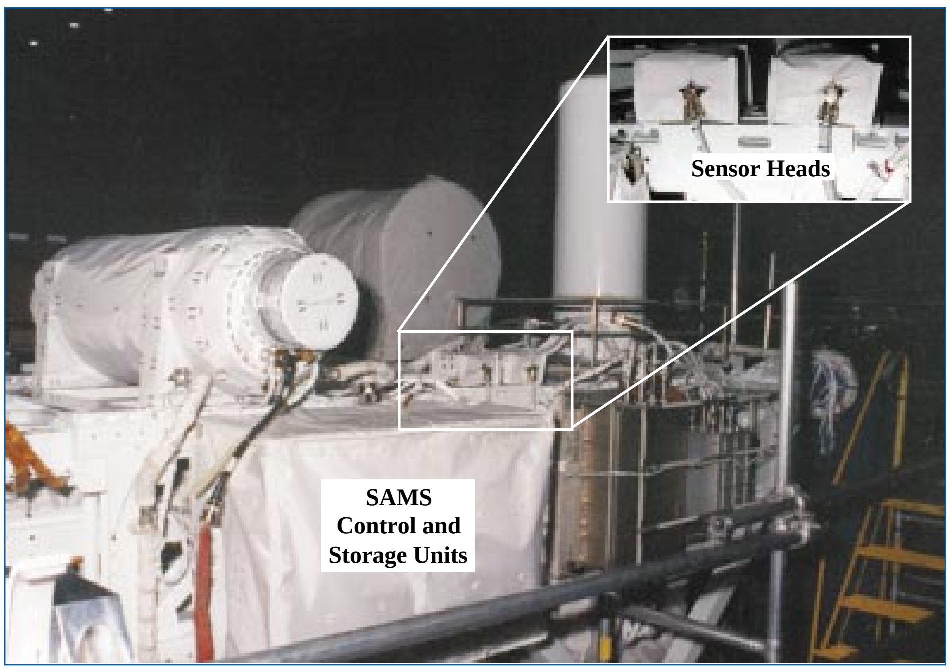
During the mission, acceleration data is transmitted to the ground in near real-time and routed to the NASA Lewis Research Center Principal Investigator Microgravity Services (PIMS) group which processes the data and displays the data for the experimenters. Based on the data they observe and the results of specialized analyses performed by PIMS, the scientists can better interpret their experiment results during the mission, can adjust their experiments if acceleration disturbances create unacceptable conditions, and can request changes to orbiter operations to take advantage of the microgravity environment.

After USMP-4, the PIMS team will analyze the data further, publish the results, and perform additional analyses at the request of the experimenters. The SAMS data will also be made available to scientists and others that may be interested through numerous other sources.

The data and the interpretation of the data analyses will be factored into the results of the USMP-4 experiments and will be used in the design of experiments for the future.

Hardware and Operations

For the USMP-4 mission, two SAMS instruments are being flown, with a total of five acceleration sensor heads. Each sensor head is made up of three single-axis accelerometers oriented so that they are mutually perpendicular. Electrical cables connect the sensor heads to the SAMS electronics package. Two computer-driven data acquisition units in the electronics packages convert the signals into digital data. All this data is transferred to hard disk drive storage on board. According to the requests of the scientists, data from some sensor heads are transmitted to the ground through the orbiter's communications systems. This downlinked data is received, processed, and displayed for the experimenters by the PIMS team.



The SAMS instrument and two of the sensor heads mounted and ready for flight

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U.S. Microgravity Payload – 4

Confined Helium Experiment (CHeX)

Science Background

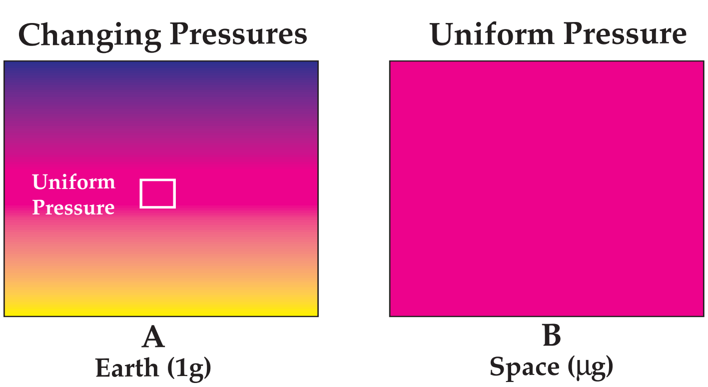
Materials normally encountered by scientists on Earth are considered to be bulk-sized or having a three-dimensional shape. The physical characteristics of these materials (their capacity to absorb heat, transmit electrical impulses, etc.) in a given shape depend only on the properties of the bulk material and the shape itself. However, when the materials are very, very thin (as found in tiny computer chips for instance), they are virtually two-dimensional; and the properties start to change and take on new values, depending upon how far away from the surface of the part the measurement is being made.

Almost daily, the semiconductor industry reduces the size of all their devices (chips, etc.) to try to improve transmission speed and power, and reduce cost. However, there obviously is a problem (as you've read above) as they change the dimensions (making them thinner and smaller) because performance values are affected. Performance is affected first by the sheer small size of the part, then by additional factors; such as, changes in part thickness and irregularities in its surface. Under its surface, material property changes are also a factor. *All* of these changes often cause defects in the final product.

On Earth, precise measurements of the size factor effects of a solid surface on material properties are almost impossible to make. For instance, their thermal properties are not uniformly dispersed throughout the sample. In addition, devices made from most materials must be so small before the size factor can be studied, that the test data is overwhelmed by all the other performance irregularities. Measurements are also affected by gravity's *pressure*, particularly as the walls or surfaces begin to "close in." The material, liquid helium, is an exception because of its "superfluidity."

Using helium in the microgravity environment of the USMP-4 mission, will help develop the knowledge needed in this fundamental area of scientific study.

Objective and Procedures



A liquid sample in Earth's gravity (A) has a non-uniform pressure distribution across it, leading to distortions in the measurement data. Microgravity eliminates the effects of gravity's pressure on measurements (B) and allows us to better probe the *underlying* physics.

Scientists for the Confined Helium Experiment (CHeX) will study one of the basic influences on the behavior and properties of materials by using liquid helium, confined between solid surfaces, and the microgravity environment of space.

Helium is unique because it has special traits that allow ultra-precise measurements, traits that are not found in other materials. As a sample of helium (normally a gas) is cooled, it becomes liquid. As the cooling process con-tinues, helium will reach its lowest possible energy state—it becomes a "superfluid." At this point, liquid helium can conduct heat 1000 times more effectively than any other material; yet, its consistency is thick (about 100,000 times thicker than possible with other materials). These properties can be produced in helium very accurately by confining it in a copper cylinder (specialized calorimeter).

The calorimeter contains a stack of 392 crystal silicon disks, each .002" thick. The disk stack forces the helium to form in very thin layers (each also .002" thick) between the disks. In addition, the cylinder measures about the same in both length and diameter, creating a two-dimensional state of the helium.

Using the microgravity environment for measuring the helium eliminates the gravity-induced pressure problem; and, a uniformity in the material is created. The uniform dispersion of the material's thermal property values; the confinement of the helium; and using an established set of temperature pulses to keep the helium near its superfluid point, allow the precise measurements needed.

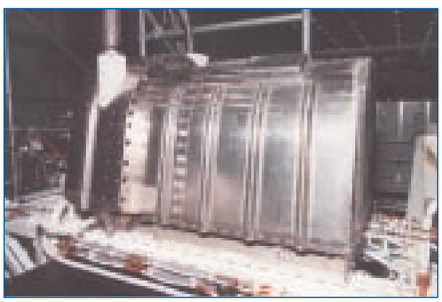
Measurements are then made of helium's temperature changes to within one billionth of a degree, or a nanodegree. Since the helium in the calorimeter has a uniform temperature, nanodegree measurements can be taken at the outside copper wall of the calorimeter (since copper is an excellent thermal conductor); thus revealing the thermal characteristics of the very thin layers of helium. These measurements will provide information required for precise calculations of the heat capacity of the liquid helium.

Scientists and industry need to understand the behavior and properties of materials. The USMP-4 mission goal is to provide a conclusive test of the current theories of how material properties should change with unprecedented accuracy.

Since electronic parts will probably continue to get smaller, finding ways to reduce product defects will develop successful devices and help industry reduce costs to the consumer.

Hardware and Operations

The CHeX hardware is composed of several main components. The container for the instrument is a double-walled facility called a dewar, which



CHeX, encased with its magnetic shield, is being readied for flight.

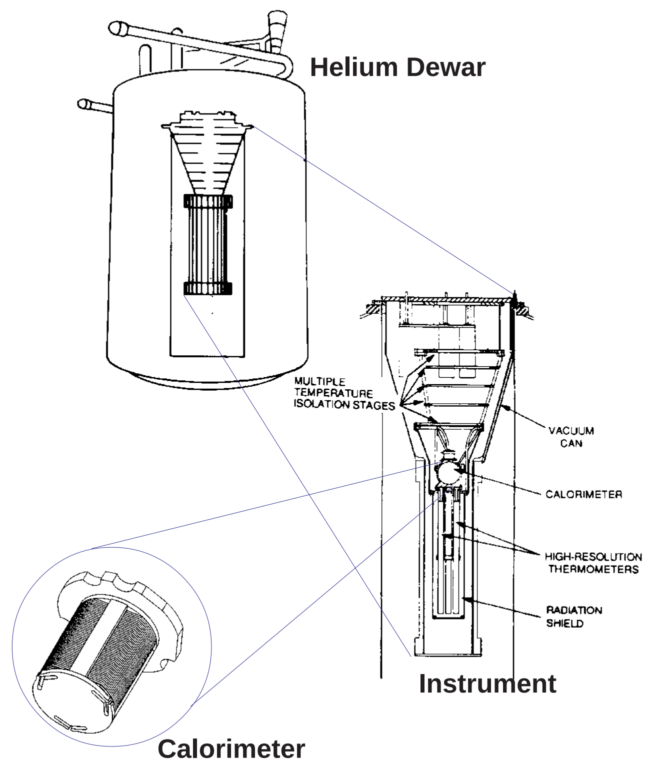
is covered on the outside by a magnetic shield. The double walls provide a vacuum between the outside and inside walls for thermal isolation of the instrument. This is similar to placing the instrument in a thermos bottle.

The research instrument is surrounded with a protective metal shroud and contains the very heart of the experiment, the cylindrical sample container (the calorimeter). Thermal controls and heater feedback systems, located in the instrument, regulate the temperature of the calorimeter sample to better than a billionth of a degree over several days.

In space, the experiment is controlled by its on-board computer, and data from the experiment is routed to the investigator team on the ground.

The CHeX experiment is extremely sensitive to environmental changes; so, the most "quiet" times of Shuttle orbits will be used for collecting the most sensitive science data.

During the mission "quiet" times, the USMP-4 science team will be able to take advantage of these science opportunities to optimize the CHeX science return.



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U.S. Microgravity Payload – 4

Orbital Acceleration Research Experiment (OARE)

Science Background

For decades, NASA has been conducting research in space. Nowhere on Earth can the experimenter find an environment that offers the distinctive characteristics available in low-Earth orbit. The free-fall conditions of orbit basically provide a gravity-free environment to all objects within the orbiter. So, the effects of gravity we feel on Earth are essentially eliminated.

Research has shown that everything in a spacecraft does have an acceleration, depending upon how close they are to the center of gravity of the Shuttle itself. These accelerations are similar to the sensations you feel when your car goes around a corner quickly and you feel like you are being thrown against the door. In space flight, these type Shuttle accelerations are of a very low-frequency and are generally referred to as the *quasi-steady* (almost steady) microgravity environment of the orbiter. Being able to measure these variations in the microgravity environment allows scientists to better evaluate the effects of space flight on their experiments. To accomplish this, the Orbital Acceleration Research Experiment (OARE) senses and records these quasi-steady accelerations.

An astronaut prepares for an engine firing often requested by scientists in order to analyze accelerations that may affect experiments.

Accelerations measured by OARE are dependent largely on location within the orbiter and the orbiter's position and motion. Precise equations can be used to estimate what the quasi-steady microgravity environment is at any location within the orbiter, using the data collected by OARE and data describing the orbiter position and motion.

In flight, scientists will utilize OARE for another method of evaluating experiment results. Researchers on the ground will request changes in orbiter position or orientation to perfect their sample growth. Being able to request these changes allows scientists to analyze the parameters of each orientation and how those parameters influenced the results of the experiments.

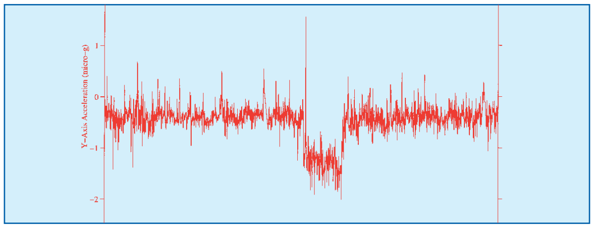
In use since 1991, the OARE has helped scientists immeasurably in obtaining crucial acceleration data. As a result of its success, NASA has manifested several flight opportunities for OARE in support of a variety of microgravity payloads. In addition, an OARE-type system will fly on the International Space Station as a part of the Space Acceleration Measurement System-II instrument supporting microgravity experiments.

Objective and Procedures

OARE's main objective is to accurately measure quasi-steady accelerations aboard the Shuttle. In addition, as the Shuttle travels around the Earth, its attitude is constantly affected and changed by atmospheric conditions. These changes are called *gravity-gradient effects*. In addition to these gravity-gradient effects, aerodynamic drag, and Orbiter rotation, OARE also senses disturbances caused by mass emissions from the Orbiter (such as venting of liquids and gases from the supply and waste water tanks, auxiliary power units, and fuel cells), and by payload bay activities.

OARE data is periodically downlinked and is routed to the NASA Lewis Research Center Principal Investigator Microgravity Services (PIMS) group, which processes the data and displays it for the experimenters. Specialized analyses can be performed for the investigators so that they can best interpret their experiment results during the mission and make any changes to their experiment operations to take advantage of the microgravity environment.

After the USMP-4 mission, the PIMS team will analyze the data further, publish the results, and perform additional analyses at the request of the experimenters. The OARE data will also be made available to scientists and others that are interested through various sources. The data and the interpretation of the data analyses will be factored into the results of USMP-4 experiments and will be used in the design of experiments for future missions.



An OARE reading showing a change in the acceleration of the Shuttle during a typical water dump

Hardware and Operations

The OARE instrument contains both software and hardware components. OARE's flight software controls the instrument and collects data during a mission; operates ground support equipment for testing the fight hardware; and recovers stored data after the mission is completed.

Typical in-flight data collection, processing, and storage is determined before the mission relative to common modes of operation and activities aboard the Shuttle—such as launch, shutdown, recapture, reentry, quiet, and normal. Transitions from one mode to the other are made by pre-set commands or through internally sensed conditions.

The OARE instrument is designed to measure, process, store, and downlink the low-frequency acceleration environment while on orbit. OARE's acceleration sensor measures various movements and accelerations throughout the mission. A number of factors may cause small changes in the OARE acceleration output, so periodic sensor calibrations are routinely made during flight.

The sensor receives commands from, and transmits data and status information to, the signal processor and control subsystem.

The OARE orbiter interface subsystem not only receives commands from the ground but also transmits data and status information to the ground.

OARE's internal structure

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U.S. Microgravity Payload – 4

Isothermal Dendritic Growth Experiment (IDGE)

Science Background

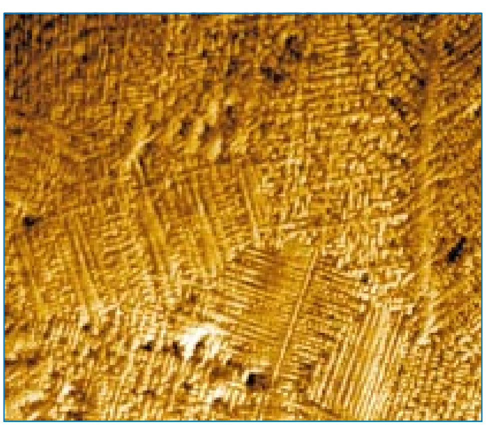
The manufacturing of many industrial and consumer products involves the process of solidification. Solidification is a material transformation familiar to everyone. Snow is a form of solid water that results from rapid cooling. Snowflakes, when viewed with a powerful microscope, take on an interesting structure made up of tree-like forms called dendrites. Dendrites (from the ancient Greek word for tree) develop as liquid materials solidify.

Most metal products solidify by forming dendrites. The size, shape, and orientation of the dendrites help determine the strength and durability of steel, aluminum, and superalloys used in the production of automobiles and airplanes. Because virtually all industrially important alloys solidify from a molten state by dendritic processes, enhancing the basic understanding of dendritic solidification may help improve industrial production techniques.

On Earth, dendritic solidification can be strongly affected by constant flows or currents in the molten materials caused by gravity. However, the effect of these flows cannot be accurately modeled without knowledge of dendritic solidification in their absence. This gravity-driven *convection* can be effectively eliminated in the microgravity environment of low-Earth orbit.

Objective and Procedures

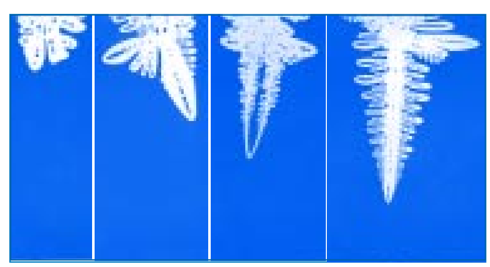
The Isothermal Dendritic Growth Experiment (IDGE) is used to study the dendritic solidification of molten materials in the microgravity environment. Metalic dendrites, in particular, grow like trees grow—with a main trunk, from which grow side branches, and a top—and continues to grow and extend branches until the tree seems to fill up most of the empty space. Studies of these metalic dendrites include the entire structure of the "tree," focusing on the branches and the top, or tip.



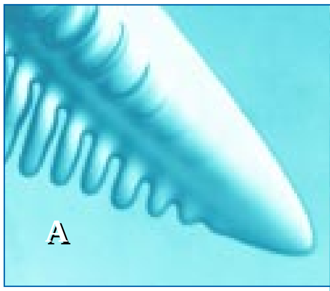
A micrograph of cast commercial brass, etched to show its microstructure (J.P.A. Lofvander, Physics Today, Oct. 1992.)

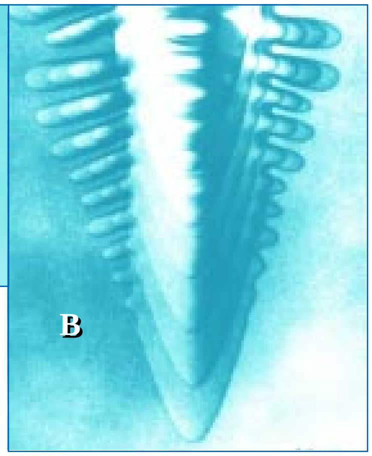
During the first two flights of IDGE on the Shuttle, the IDGE flight hardware grew and photographed individual dendrites of the material succinonitrile (SCN) as they solidified at various temperatures. SCN mimics the behavior of metals, but is transparent, allowing photography of the dendrites.

The IDGE scientists compared photographs of space-grown dendrites with photographs of dendrites grown on Earth. They found that on Earth, convection dominated and increased the speed of dendritic growth, especially in the cooling ranges typical of metal casting; and basically prevented any straightforward analysis. At the same low cooling ranges in microgravity free of convection, the science team collected twice the data they needed, significantly improving the analyses that could be performed.



Time-lapsed photography of dendritic growth in space



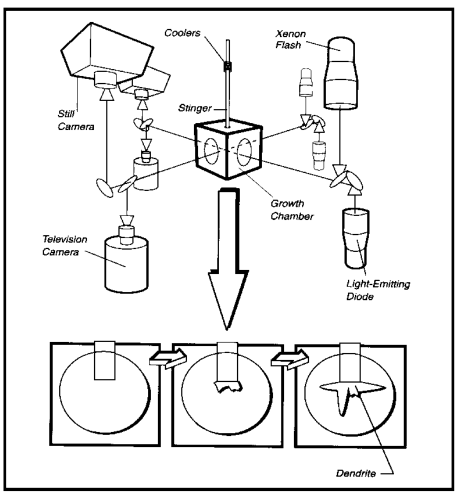


A SCN dendrite:
(A) Earth-grown and
(B) space-grown

The third flight of IDGE (USMP-4) will utilize a different sample material, pivalic acid (PVA). PVA has a much stronger tendency to grow along the primary dendritic "tip" direction, rather than in the "branch" direction (SCN). This will allow a more detailed study of the tip radius than was possible with SCN under the same growth conditions. This information will provide a key element in understanding how materials solidify via dendritic processes.

Hardware and Operations

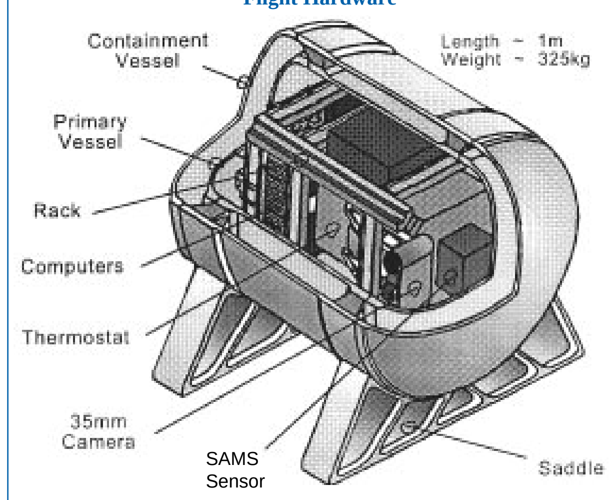
The IDGE apparatus consists of a thermostat that contains the dendrite growth chamber. The growth chamber is filled with ultrapure PVA



before flight and contains a stinger that is used to begin dendrite growth. The stinger is a hollow tube filled with PVA connected to coolers on the outside of the growth chamber. As the stinger is cooled, the PVA in the tube begins to solidify. The solidification front moves down the tube to the tip of the stinger and emerges into the PVA volume as an individual dendrite.

Two television cameras "watch" for the emergence of the dendrite. When software in the IDGE computer detects dendrites, it triggers two 35 mm cameras, which photograph the growing dendrites in a programmed sequence. In addition, a video cassette recorder housed within the IDGE apparatus, begins recording the dendrite as it grows. The television images are also transmitted to the IDGE science team on the ground. As many as 120 dendritic growth cycles will be carried out during the USMP-4 mission.

Flight Hardware



Loading and preparing for tests

IDGE mounted on the carrier and ready for flight

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U.S. Microgravity Payload – 4

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For the Future . . .

Space research in the years ahead will stress both scientific and commercial goals. Processes will include solidification of metals and alloys, as well as transporting fluids and chemicals in microgravity. As research in these areas develops, the benefits will become increasingly apparent on Earth: new materials, more efficient use of fuel resources, new medicines, advanced computers and lasers, and better communications.

Like space, opportunities offered by microgravity science are vast, and are only beginning to be explored.